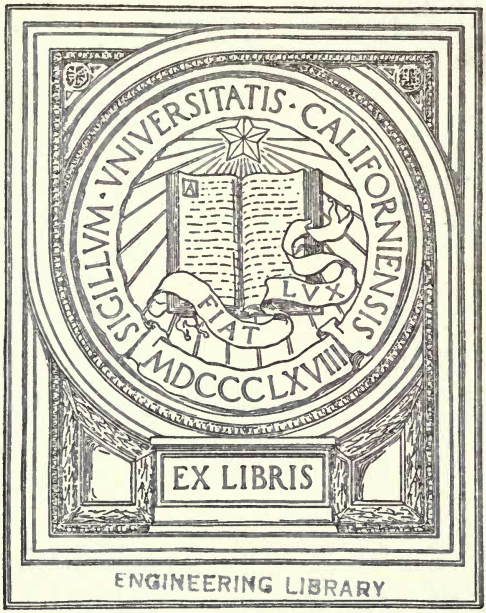


For Miss Meek
With the compliments of
the Author.



# REPORT

## UPON

# THE SANITARY QUALITY

## OF THE

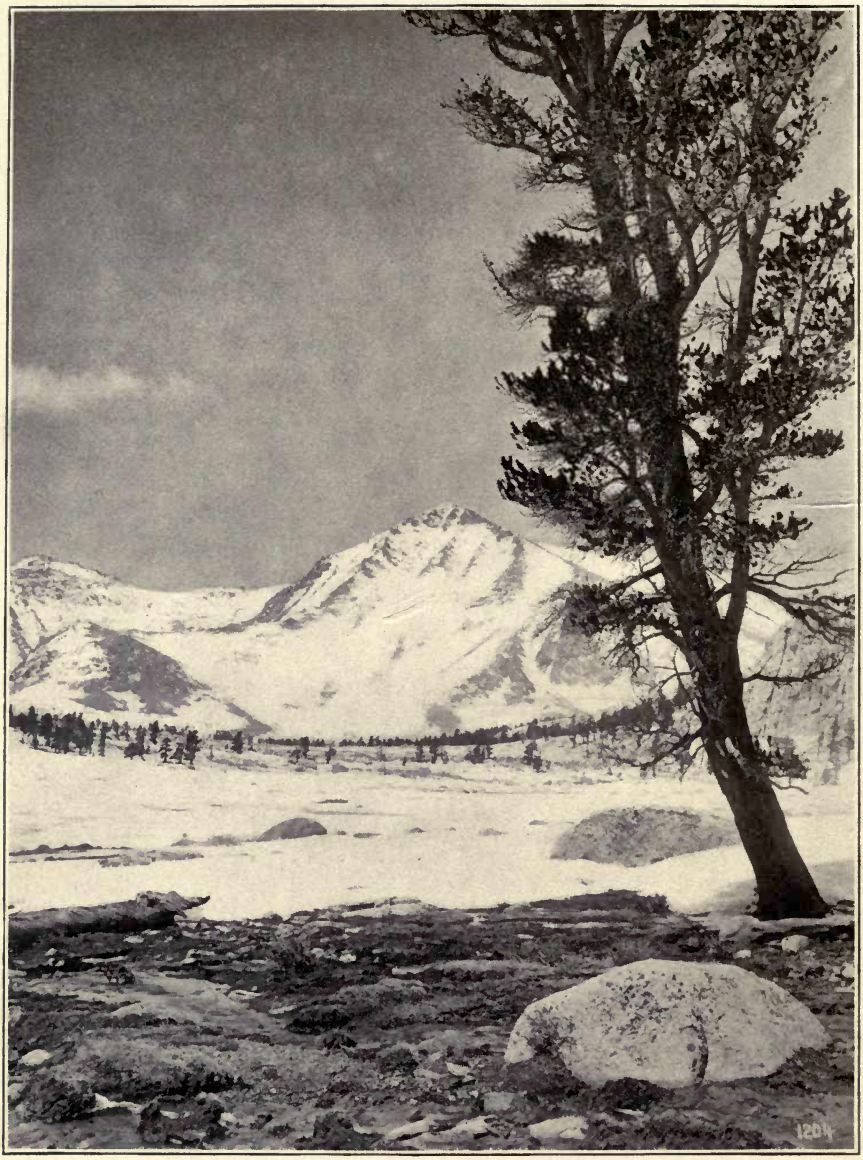
# OWENS RIVER WATER SUPPLY

BY

CHARLES GILMAN HYDE
**Sanitary and Hydraulic Engineer**



**Reprinted from the Fourteenth Annual Report of the Board of Public Service Commissioners of the City of Los Angeles, California**




HEAD OF COTTONWOOD CREEK, JUNE 7, 1915
(DRAINAGE IS TRIBUTARY TO THE LOS ANGELES AQUEDUCT)

# REPORT

UPON

## The Sanitary Quality of the Owens River Water Supply Delivered to Consumers in Los Angeles Through the Los Angeles Aqueduct System

BY

CHARLES GILMAN HYDE
*Sanitary and Hydraulic Engineer*

LOS ANGELES, CALIFORNIA
1915

Reprinted from the Fourteenth Annual Report of the Board of Public Service Commissioners of the City of Los Angeles, Cal.

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by

CHARLES GILMAN HYDE,
Sanitary and Hydraulic Engineer.

July 1, 1915.

## LEGAL FEATURES OF CASES.

### ANTAGONISM TO AQUEDUCT PROJECT.

The conception of a great system of water supply from Owens River for the people of Los Angeles was nothing less than an inspiration. Its construction has required faith, loyalty, brains and engineering ability of the highest order. Its consummation spells for the citizens of Los Angeles a degree of success and a brilliancy of future which could in no other way have been so perfectly vouchsafed.

Yet from the beginning all sorts of selfish interests have antagonized the development of this magnificent project. These interests have for the most part waged a battle from the ambush. They have used the knife in the dark. They have not permitted their identity to be disclosed. Mere dummies posing as citizens jealous of the welfare of the people or as public-spirited engineers have served as screens for the "malefactors of great wealth" who would have been able to profit if this scheme of water supply could have been throttled or if spurious claims to water in the Owens River drainage basin could have been foisted upon the city at great cost. Fortunately, the construction of the works was not thereby halted. The engineers and attorneys for the city and the real citizenship which had the best interests of the city at heart did not falter. They carried the enterprise through according to the original program of capital outlay, capacity of works and time schedule.

It remained for one final, but again futile, effort to be made to destroy the project at or about the time when, the aqueduct and reservoirs having been sufficiently completed, the water was finally brought to the threshold of the City and turned into the distribution system. This attempt to undermine or destroy the efficacy of the Aqueduct system took the form of injunction proceedings to restrain the further use of water from Owens River.

### MOTIONS FOR INJUNCTION AGAINST USE OF OWENS RIVER WATER.

The first suit, including a motion for a preliminary injunction, was filed in the Superior Court of Los Angeles County on or about August 15, 1914, by Henry A. Hart. Mr. Hart was the leader of the mal-odorous majority of the Peoples Aqueduct Investigation Board, so-called, whose work and report are too well remembered to require extended mention here. It is sufficient to state that, after having been in existence for six months and having spent $16,535.48 in "investigating," they were unable to find

any evidence of graft or incompetence in the prosecution of the aqueduct project. They were willing to go on record, however, as being certain, on the basis of their intimate knowledge of human nature, that were they to be continued in office for a sufficiently longer period with sufficiently larger sums to expend, tangible evidences of graft and incompetence would be forthcoming.

It was shortly discovered that no sufficient cause of action existed in Hart's case because he was not a resident within the territory supplied with aqueduct water, which was a principal ground of complaint. A second suit was therefore filed in behalf of Edgar M. Frost, who seemed to be willing to serve as a dummy plaintiff and who conveniently lived in the district which was being supplied with water from Owens River. Furthermore, among other activities, Frost was employed as a detective in the office of attorney for plaintiff during the period covered by the suit.

The suits were brought by Mr. Ingle Carpenter, as attorney. The names of the clients in whose interests he served Mr. Carpenter has not yet seen fit to divulge, nor did they appear during the hearing of the case.

As a self-styled servant of the people Mr. Carpenter made a trip into the Owens Valley region in June, 1914. In July he employed Dr. Ethel Leonard as a sanitary expert and accompanied her on a six days' inspection trip over the watershed. A few samples for bacteriological and chemical examination, and a few photographs, were taken at this time. Upon her return to Los Angeles, Dr. Leonard prepared a report of her sanitary investigations. This was shortly printed and, consistently enough, was clothed in yellow covers. It was spread broadcast throughout the city and country "wherever it could do the most harm."

The original motion for a preliminary injunction was supported by seven affidavits filed by H. A. Hart as plaintiff, Ingle Carpenter as attorney, Dr. Ethel Leonard as sanitary expert, Ralph Leonard as assistant, Dr. A. F. Wagner as chemist, H. R. Fosbinder as veterinarian, and G. L. Hazlett as searcher of records. These affidavits were variously dated between August 7th and 13th. The order to show cause why the injunction should not be granted was signed by Judge Lewis R. Works as Presiding Judge of the Superior Court, under date of August 15th, and required the defendants in the action, the City of Los Angeles and the individual members of the Board of Public Service Commissioners, to appear in Court on August 26th. The representatives of the parties appeared but the hearing on the motion for a preliminary injunction was postponed on account of the absence of Dr. Ethel Leonard, who departed for Chicago immediately after making her report, above noted. Judge Works then decided that no preliminary injunction should be issued and that the case should be set down for an early trial.

A second suit was filed on behalf of Edgar M. Frost on October 5, 1914. The summons was dated October 5th and required that the defendants appear and answer within ten days thereafter.

AFFIDAVIT OF DR. ETHEL LEONARD.

The principal affidavit in support of the motion of H. A. Hart looking to a preliminary injunction, restraining the further use of Owens River water through the Aqueduct system, was that of Dr. Leonard. This paper

was almost identical with the printed report above mentioned. Something of the profound technical ability of this expert for the plaintiff, and something of the animus actuating her work, may be inferred from the following statements in the affidavit in question:

> "Although cultures"—of Horton's creek water—"made by the State Hygienic laboratory showed the presence of typhoid bacilli, the source of infection and virulence of the organisms could not be accounted for." No samples from this source were ever examined by the State Hygienic Laboratory. Moreover, neither this laboratory nor any other reputable laboratory attempts to differentiate B. typhosus in routine work and but few authentic isolations of this germ have ever been made from potable waters.
>
> "Physical conditions"—at the north end of Haiwee Reservoir—"demonstrate beyond question that even bacteria cannot develop in such polluted water."
>
> "The course of these creeks"—mountain streams emptying into Long Valley—"lies through the marshes of Long Valley which contain enumerable"—(innumerable)—"dead cattle." The testimony in the case showed that only two or three carcasses of varying ages were discovered in an area fully 20 square miles in extent.
>
> "Owing to the large number of germs and contamination by organic matter found in practically all of the samples, it was deemed inadvisable and impractical to attempt to segregate the specific pathogenic bacteria." The real reason should lie in the limitations of bacteriological procedure, not in the causes named.
>
> "The inoculation of the Owens River water from its source to the intake with pathogenic and saprophytic bacteria must so alter its chemical condition that the continued use by the residents of Los Angeles for human consumption and domestic use, even with boiling precautions, must necessarily result in severe gastro-intestinal diseases. Other diseases resulting from disturbed metabolism will undoubtedly attack anyone who continuously drinks this water."
>
> "My investigation shows that any use of Owens River water is absolutely impossible from a sanitary standpoint."
>
> "Plate cultures all developed 72 hours before colonies were counted." "Cultures were kept as near as possible at a uniform temperature, 37°C." The period of incubation employed by Dr. Leonard was three times as great as American standard methods dictate.

COMPLAINT OF EDGAR M. FROST.

The complaint of Edgar M. Frost, upon which the second suit was based, made the following principal allegations:

(1) that the City of Los Angeles, a municipal corporation, through the Board of Public Service Commissioners, who have immediate charge of the water works system, furnishes as a portion of its supply, the water from Owens River through the Los Angeles Aqueduct.
(2) that the plaintiff is furnished with water from this source which is alleged to be polluted in various designated ways above the point of intake and is therefore unhealthful to consumers in the City of Los Angeles.
(3) that certain streams such as Cottonwood Creek are unpolluted and sufficient for present purposes and that the supply can be extended by the use of other protected creeks.
(4) that no permit had been obtained from the State Board of Health.
(5) that the supply derived from Los Angeles River has hitherto been unpolluted and healthful, but now has become polluted by the turning of Owens River water into the distribution system.
(6) that various chemical and bacteriological analyses made in behalf of the plaintiff on samples collected from the system as far down

as San Fernando Valley show the water to be polluted and therefore dangerous and unhealthful to consumers in the City of Los Angeles and to the plaintiff.

During the trial, the falsity of every statement named above, except (1), (4), and the first part of (5), was demonstrated beyond peradventure. With respect to item (4) Judge Works declared that the statute which appears to require that a permit to operate the works must be secured from the State Board of Health is either unconstitutional or else was covered by charter provisions since the Los Angeles City charter confers on the City the right and power both to acquire and to operate and control a water works system.

HEARING BEFORE JUDGE WORKS.

The Hart and Frost cases were assigned by Judge Works to himself. After several postponements, all at the instance of Ingle Carpenter, attorney for the plaintiffs, the trial of both cases was begun on January 5th, it being agreed that the cases be tried together. The trial continued with few interruptions until the decision was rendered on March 19th. The hearing consumed 40 court days. The transcript embraced some 6,312 pages and possibly 1,250,000 words.

In its relation to the best interests and the general welfare of the people, the capital outlay involved and the number of trained experts employed, this litigation represents one of the most important cases yet heard in the United States dealing wholly with a water supply problem. From the standpoint of the significance and complexity of the sanitary principles involved, as well as from the standpoint of its general importance, this litigation is outranked by the famous Chicago Drainage Canal Case (State of Missouri vs. the State of Illinois and the Sanitary District of Chicago, 1900-1906) which comprehended problems of sewage disposal as well as of water supply. In volume of testimony and the number of trained experts employed this litigation is to be compared with the Jersey City Water Supply Case (City of Jersey City vs. Jersey City Water Supply Company, 1904-1908).

Throughout the trial Judge Works proved himself to be most fair. He was extremely generous in the admission of testimony from both sides. He was tireless in his attention to every detail and angle of the case. Because of his extremely judicial temperament and his clear grasp of the problems as presented to him, his decision must be considered to be practically faultless and impregnable.

The case was most ably conducted for the city by Mr. W. B. Mathews, Special Counsel to the Board of Public Service Commissioners, assisted by Mr. Wm. B. Himrod, Deputy City Attorney. The experts testifying in behalf of the City were Wm. Mulholland, Chief Engineer of the Board of Public Service Commissioners, and Dr. Stanley Black, Dr. Walter V. Brem, Charles Gilman Hyde, Dr. Edwin O. Jordan, Charles H. Lee, E. O. Slater, and Carl Wilson. Testimony on certain engineering and operative features of the Aqueduct system was given by Messrs. Van Norman, Shuey and Jones of the Aqueduct staff.

The case for the plaintiffs was conducted by Mr. Ingle Carpenter, attorney. The experts testifying in behalf of the plaintiffs were Dr. Ethel


NORTH TWIN LAKE, LOOKING SOUTH
(TRIBUTARY TO THE OWENS RIVER)

Leonard and Dr. Ernst A. Victors. The testimony on behalf of plaintiffs on certain engineering features of the case was given by Messrs. R. E. Child, H. E. Linden, and Cyril Williams.

## BRIEF DESCRIPTION OF AQUEDUCT SYSTEM.

### SOURCES OF SUPPLY.

The principal sources of supply of water to the aqueduct system are, or will be:—(1) Owens River, taken about half-way between the villages of Big Pine and Independence, and about 257 miles via the aqueduct works from Los Angeles; (2) Black Rock Springs, tributary to the line of open aqueduct above Haiwee Reservoir about three miles below the intake on Owens River; (3) Cottonwood Creek and some thirteen other smaller creeks tributary to the line of open aqueduct; (4) A large volume of artesian water to be taken in the future, when necessary, from wells sunk along the west side of the open aqueduct in the Independence region.

It is considered to be unnecessary to discuss herein the yield of these various sources of supply. It may be stated that the works have been so designed that any or all of these sources may be drawn upon at will. Only a few wells have as yet been developed. The flow from these is regularly taken into the aqueduct. The line of open aqueduct north of Haiwee Reservoir is completely controllable by gates so that as much or as little water may be diverted from Owens River and the tributary creeks as may be desired, limited, of course, to their respective yields.

### ELEMENTS OF SYSTEM OF WORKS.

In order that the contentions of the City and the findings of the Court as respects the quality of water finally delivered to consumers in Los Angeles may be understood, it is necessary that a fairly comprehensive idea be had concerning the system of works comprised in the aqueduct project, especially with reference to their capacity and dimensions. The system may be roughly outlined as follows:—

(1) An intake on Owens River about 15 miles north of Independence, the county seat of Inyo County. The drainage area tributary to this point is estimated to be about 2740 square miles. The elevation is 3814.8 feet. The intake is so designed that as much or as little water as is desired may be diverted from the River.

(2) A line of open aqueduct 60.8 miles in length from the intake on Owens River to the north end of Haiwee Reservoir. The upper or northerly portion of this aqueduct, comprising about 23.72 miles, is an unlined ditch; the remainder or southerly portion is lined with concrete. Throughout its entire length, this stretch of open aqueduct is protected by a substantial barbed wire fence. All bridge crossings are properly enclosed. The carrying capacity of this section of the aqueduct is 580 million gallons per day. The rate of flow is estimated to vary from an average of about 1.1 feet per second, with a draft of 26 million gallons per day, to 2.8 feet per second when the draft reaches 272 million gallons. This section of the aqueduct is provided with various diversion and regulating gates whereby the amount and character of the water entering it or flowing therein may be controlled.

(3) Haiwee Reservoir with high water elevation of 3760 feet. This reservoir consists virtually of three great elongated basins connected by narrow straits. Taken as a whole it is sinuous. The

banks are bold, steep, and deeply incised by ancient erosion. The immediate watershed is small, uninhabited, practically rainless, a desert and almost without run-off. The only waters reaching this reservoir in significant amount must arrive through the open aqueduct discharging into the north end. The intake by which the water must leave the reservoir is located at the extreme southerly end. Practically all water entering the reservoir must traverse its entire length of 7.25 miles before it can escape through the intake into the line of aqueduct below. The reservoir has an average width of about 2400 feet and an average depth of 30 feet. The area of water surface at the high water line is 2100 acres or nearly 3.3 square miles. It has been created by two hydraulic-fill dams, one at either end. The maximum depth of water at the north dam or inlet end is 28 feet; that at the south dam or intake end is 64 feet. The capacity of this great reservoir, when filled to the high water line, is 20,800 million gallons.

This reservoir is indeed unique among the storage reservoirs of the world. There is believed to be no other reservoir in existance on a similar or anything like a similar scale of magnitude where the inflow is absolutely controllable because of the fact that it is not filled from its own watershed. The danger of short-circuiting when maintained with a reasonable depth of water is therefore absolutely eliminated.

(4) About 135.5 miles of aqueduct from the south end of Haiwee Reservoir to Fairmont Reservoir. For about 2 miles immediately below Haiwee Reservoir the aqueduct consists of an open concrete-lined ditch. The remainder of the distance is comprised of concrete-lined covered aqueduct, concrete-lined tunnels and riveted steel inverted siphons. The carrying capacity of this section is 272 million gallons per 24 hours, and the velocity of flow varies from an average of about 2.7 feet per second, with a draft of 26 million gallons per day, to about 5.3 feet per second when the draft becomes 272 million gallons daily.

(5) Fairmont Reservoir, with a proposed high water elevation, when completed, of 3025 feet. This reservoir is being created by an hydraulic-fill dam which has not yet been raised to the ultimate height proposed. The present storage capacity is about 277 million gallons. The distance from inlet to outlet is about 0.4 mile. When completed the reservoir capacity will be 1940 million gallons. This basin will serve as a huge forebay for the San Francisquito power plant.

(6) About 17.6 miles of concrete-lined and covered aqueduct, concrete-lined tunnels and riveted steel pipe lines from Fairmont Reservoir to Dry Canyon Reservoir. At the present time a portion of these works are under construction, and ever since the plant has been in service the water has been allowed to flow for a distance of about 9 miles through the San Francisquito Canyon to the location of the tunnel below the power house. (Since the above was written, the tunnels in San Francisquito Canyon have been completed and the natural stream bed of the canyon is only used for a distance of about one and one-half miles in an inaccessible gorge in hard granite rock, which imparts no objectionable character to the water.) The capacity of the conduits in this section is about 650 million gallons per 24 hours. The rate of flow is estimated to vary from a general average of 2.4 feet per second, with a daily draft of 26 million gallons, to 4.8 feet per second when the average draft becomes 272 million gallons per day.

(7) Dry Canyon Reservoir with high water elevation of 1505 feet. This reservoir has been created by an hydraulic-fill dam. The storage capacity is 430 million gallons. The distance from inlet to outlet is about 0.7 mile. This basin will serve as an equalizing

reservoir to compensate for variations in draft on the part of the power plant in San Francisquito Canyon and on the part of the City.

(8) About 11.5 miles of covered aqueduct, lined tunnels and riveted steel pipe lines from Dry Canyon Reservoir to the Cascades, thence about 1.6 miles of open lined ditch to the inlets of the San Fernando Reservoirs. The capacity of the conduits in this section is 272 million gallons per 24 hours. The rate of flow is estimated to vary from an average of about 2.7 feet per second, with a daily draft of 26 million gallons, to about 5.4 feet per second when the aqueduct is delivering at its full rated capacity.

(9) San Fernando Reservoir No. 1 with a proposed high water elevation of 1265 feet, a length between inlet and intake of 0.7 mile, and a capacity of 4,900 million gallons. This reservoir has not yet been constructed.

(10) San Fernando Reservoir No. 2 with a proposed high water elevation of 1135 feet, a length between inlet and intake of 1.4 miles, and a capacity of 7,500 million gallons. This reservoir is being created by the erection of a high hydraulic-fill dam. This reservoir will be by-passed and will not form a component part of the works, as now proposed, delivering water into the present distribution system in Los Angeles.

(11) About 12.8 miles of concrete-lined tunnel and riveted steel pipe line from San Fernando Reservoir No. 1 to the inlet of Upper Franklin Reservoir. The capacity of this conduit is 97 million gallons daily. The rate of flow therein is estimated to vary from about 1.0 foot per second, with a draft of 26 million gallons per day, to about 7.4 feet per second with a daily draft equal to the capacity of the conduit.

(12) Upper Franklin Reservoir with high water elevation of 850 feet, a length between inlet and intake of 0.25 mile and a capacity of 42 million gallons. This basin has been created by an hydraulic-fill dam to serve as a distributing reservoir for the City.

(13) About 1.1 miles of riveted steel conduit from the intake of Upper Franklin Reservoir to the inlet of Lower Franklin Reservoir. This pipe line has a carrying capacity of 39 million gallons per 24 hours. The velocity therein will vary from about 3.1 feet per second, with a draft of 26 million gallons per day, to about 8.6 feet per second when flowing at its rated capacity.

(14) Lower Franklin Reservoir with a proposed high water elevation of 575 feet, a length from inlet to intake of 0.63 mile and a capacity of 360 million gallons. This reservoir is now under construction. It is being created by an hydraulic-fill dam. Like Upper Franklin Reservoir this basin will serve as a distributing reservoir for the City.

(15) A main riveted steel pipe line about 7.0 miles in length connecting Lower Franklin Reservoir with the district in Los Angeles supplied from the aqueduct system. This line has a rated carrying capacity of 26 million gallons per day. When delivering this volume of water the velocity therein is about 3.1 feet per second. It can deliver 40 million gallons per day, at which rate the velocity in the pipe line would require to be 5.3 feet per second.

## STORAGE CAPACITY AND STORAGE PERIOD.

The total storage capacity of the reservoirs now built and building, through which water supplied to consumers in Los Angeles must pass on its way from the source of supply in Owens Valley, is 23,570 million gallons. From the data just presented, it is possible to calculate the time

factor in the conduits and reservoirs of the system with the exception of the storage period in Haiwee Reservoir. If maintained half full of water this will never be less than 38 days with an ultimate development of works represented by 272 million gallons per day. With the use of water at the rate of 26 million gallons daily, as at present, the storage period at half capacity is 402 days. The storage periods with the reservoir maintained full of water would be double the figures just given.

Other reservoirs are possible and are proposed in the ultimate system of works. With these in service the storage periods would be vastly prolonged.

THE SOURCE OF SUPPLY FROM A SANITARY STANDPOINT.

GENERAL CONSIDERATIONS.

The fundamental factor determining the degree of significant pollution of any given source of water supply is the extent to which it does or may receive the foecal wastes from human beings. Man himself is the chief agent of infection of mankind. Animal infection is relatively unimportant and especially so when matters of water supply and the diseases which are water borne are considered. A moderate amount of organic matter in water, in the absence of pathogenic bacteria, must be considered as entirely harmless and without significance. Long human experience with waters charged to varying degrees with the organic matter in question has demonstrated beyond peradventure the fact just stated.

Theoretically the germs of one serious animal disease may be carried by water and may cause sickness among human beings. This disease is anthrax. Throughout the hearing of the case the counsel for the plaintiffs attempted to make a strong point of this feature since anthrax to a limited extent has occurred among cattle in the Owens Valley. The annals of hygiene, however, fail to record one single case of human anthrax which can be attributed to the drinking of an infected water supply.

It remains therefore to examine the conditions prevailing within the drainage basin of the aqueduct supply to determine the extent to which human and perhaps animal foecal wastes do or may enter the streams and cause their contamination. Furthermore, all of the conditions of self-purification of these waters must be examined to determine the likelihood of the survival of any pathogenic bacteria, should such enter the supply above Haiwee Reservoir, until the water is delivered to consumers in Los Angeles.

Between the inlet of Haiwee Reservoir and the distribution system in Los Angeles, a distance of 196.2 miles via the aqueduct works, involving a chain of at least five reservoirs and perhaps six, there is not one permanent source of contamination of the aqueduct water. The only temporary source of possible contamination is the course of San Francisquito Canyon for a distance of nine miles (*), wherein the aqueduct waters are or have been allowed to flow during the period required for the construction of certain tunnels, fore-bay, pen-stocks, power-house and tail works in this section. This section is practically uninhabited except for the aqueduct construction camps near the power house site. The canyon is traversed by a county road which sustains some small amount of travel.

(*) See item 6, page 38.

AREA AND EXTENT OF WATERSHED.

The total drainage area tributary to Owens River above the intake of the aqueduct is estimated to be 2740 square miles. That tributary to the inlet of Haiwee Reservoir is about 3350 square miles, including 500 square miles in the watershed of Cottonwood Creek above the line of the aqueduct. The drainage area directly tributary to Haiwee Reservoir is perhaps 60 square miles. In general the westerly portion of the drainage basin comprising the easterly slopes of the Sierra Nevada Mountains is the only part from which there is any considerable run-off. The easterly portion of the drainage basin is comprised of the dry, arid westerly slopes of the White and Inyo Mountains.

RESIDENT POPULATION AND ITS DISPOSITION IN THE DRAINAGE BASIN.

The total population resident in the drainage basin of Owens River above Haiwee Reservoir is estimated to be about 4600 at the present time. Roughly speaking the bulk of this population is grouped in four districts, as follows: in Round Valley, in and around Bishop, in and around Big Pine, and in and around Independence. There are perhaps 1150 dwellings within the drainage basin and of these fully 650 are scattered and are outside of the villages just named. From figures presented in the last Federal census reports it is estimated that there are not more than 350 farm or ranch houses in this entire area of 3350 square miles in question. It will be seen that the average density of population is but 1.4 persons per square mile.

There is scarcely a large impounding reservoir in the United States on whose watershed the population is so sparse as that tributary to the Los Angeles Aqueduct at Haiwee Reservoir. The average density of population on 77 reservoir watersheds in Massachusetts, a state of notably excellent and safe water supplies, is 132 per square mile. The density of population on the reservoir drainage basins of Boston, Worcester, Fall River, New Bedford and Brockton, Mass., and Rochester and Syracuse, New York, ranges from 21 to 210 times as great as that upon the watershed tributary to Haiwee Reservoir. In none of these cases is the water purified and made safe in any other way than by storage. In none of these cases is a reservoir filled by any other way than from its own watershed under conditions, especially as regards flood, which are not controllable.

There is but one incorporated place on the drainage area above Haiwee Reservoir. This is the little City of Bishop, estimated to have a population of 1500 at present. There are but two unincorporated hamlets or villages in the drainage area. These are Big Pine, having a population of perhaps 300, and Independence, the County seat, having a population of 200.

From the best statistics available it appears that the animal (domestic) population of the area is 35,700, of which 40% are cattle and 38% sheep and goats. On the average there is one domestic animal to every 60 acres in the drainage area.

NATURE AND EXTENT OF POLLUTION.

The City of Bishop is provided with a sewerage system serving approximately two-thirds of the population or perhaps 1,000 persons. On account of the high ground water in this district, the sewers have been underdrained. The underdrains for some unaccountable reason have been arranged to dis-

charge into the sanitary sewers at the manholes. In consequence the flow is relatively very large and the sewage is correspondingly very weak. The present total daily flow of sewage is perhaps 500,000 gallons, or 500 gallons per capita connected with the sewers. The sewage is treated in a septic tank of the Cameron type, and the effluent is discharged through ditches upon land. For the most part it disappears through seepage into the coarse gravelly soil, but at times at least a portion of it overflows lands to the southeast of the septic tank and enters a slough which, after a long course with many interruptions in the shape of ponds, lagoons and marshes, reaches Owens River or Big Pine Canal, according to conditions. If received into Big Pine Canal, which is believed generally to be the case, it is carried far to the south where it disappears entirely through seepage and does not enter Owens River or any of its direct tributaries. Just east of the location of the septic tank there is a low ridge of sandy land which mechanical analyses of properly collected samples show to be perfectly adapted to sewage disposal by intermittent sand filtration. The sewage of Bishop could unquestionably be disposed of in a most effective and innocuous way upon filter beds properly constructed and operated upon the site in question.

Five hundred persons in the town of Bishop and the remaining 3100 persons elsewhere in the drainage area are provided with privies. It seemed to be possible to find but one privy in all this number, namely 900, which discharged its contents directly into any natural stream or irrigation canal. The exception noted was at once suppressed. It is doubtful if there is another equivalent number of inhabitants in rural America who have so completely refrained, as have the people in Owens Valley, from directly polluting the local streams and irrigating waters. In a very few instances investigation showed that privies were in existence at distances as small as from 4 to 6 feet of controllable water courses, such as irrigation ditches, but the vast majority, say fully 95%, were located at substantial distances from such water courses.

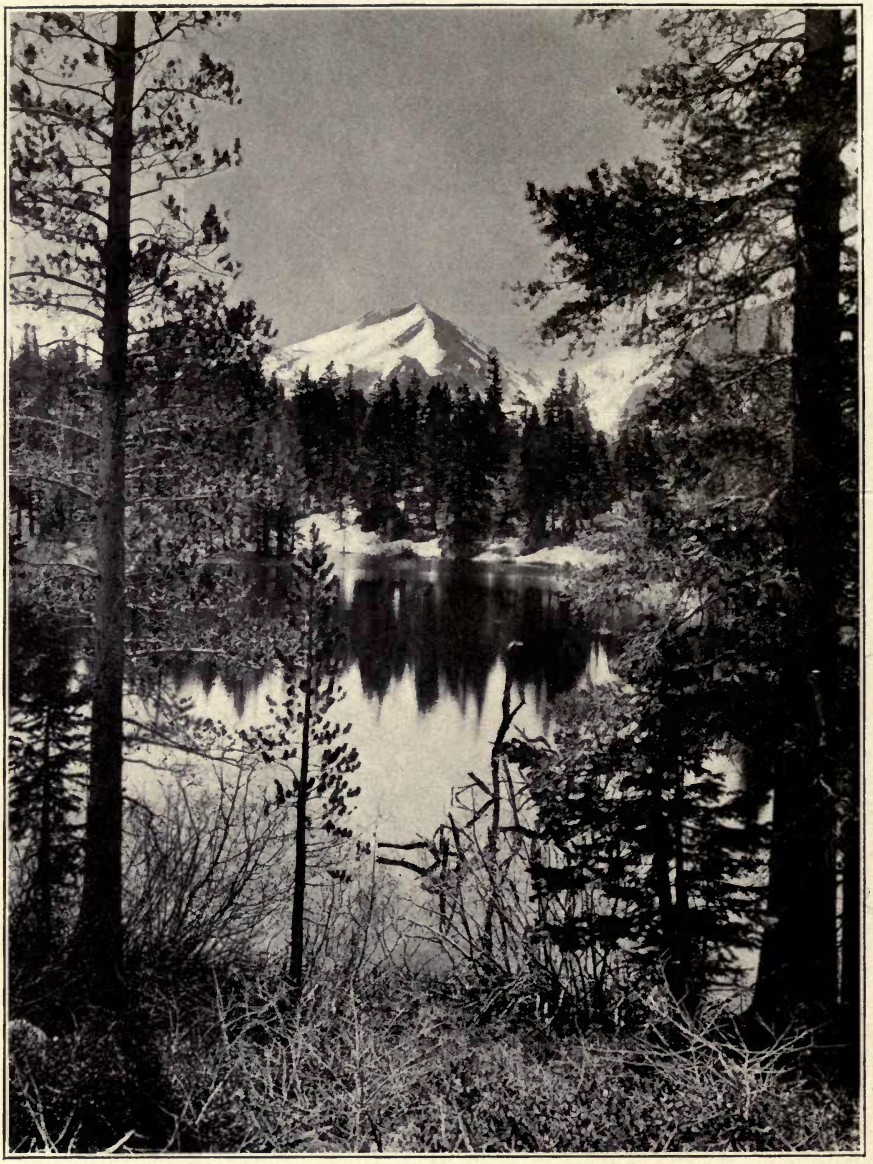
It has become the custom in Owens Valley to build stock corrals immediately adjacent to natural streams or with irrigation ditches passing through them. In a very few of these corrals it is possible that considerable amounts of manure may be washed by very heavy rains or high water into the streams. A careful study of the conditions has shown that in the majority of cases the water courses passing through the corrals are irrigation ditches and are controllable with respect to the volume of water flowing therein. In very many instances these ditches are above the general level of the corrals.

It can be stated positively that the conditions within the drainage area tributary to the Los Angeles aqueduct above Haiwee Reservoir are unusually good, for rural communities, with respect to the amount of human or animal contamination of the water supply. Furthermore, the conditions are such that, with a minimum expenditure of time and money, through sanitary inspection, the conditions can be made thoroughly satisfactory.

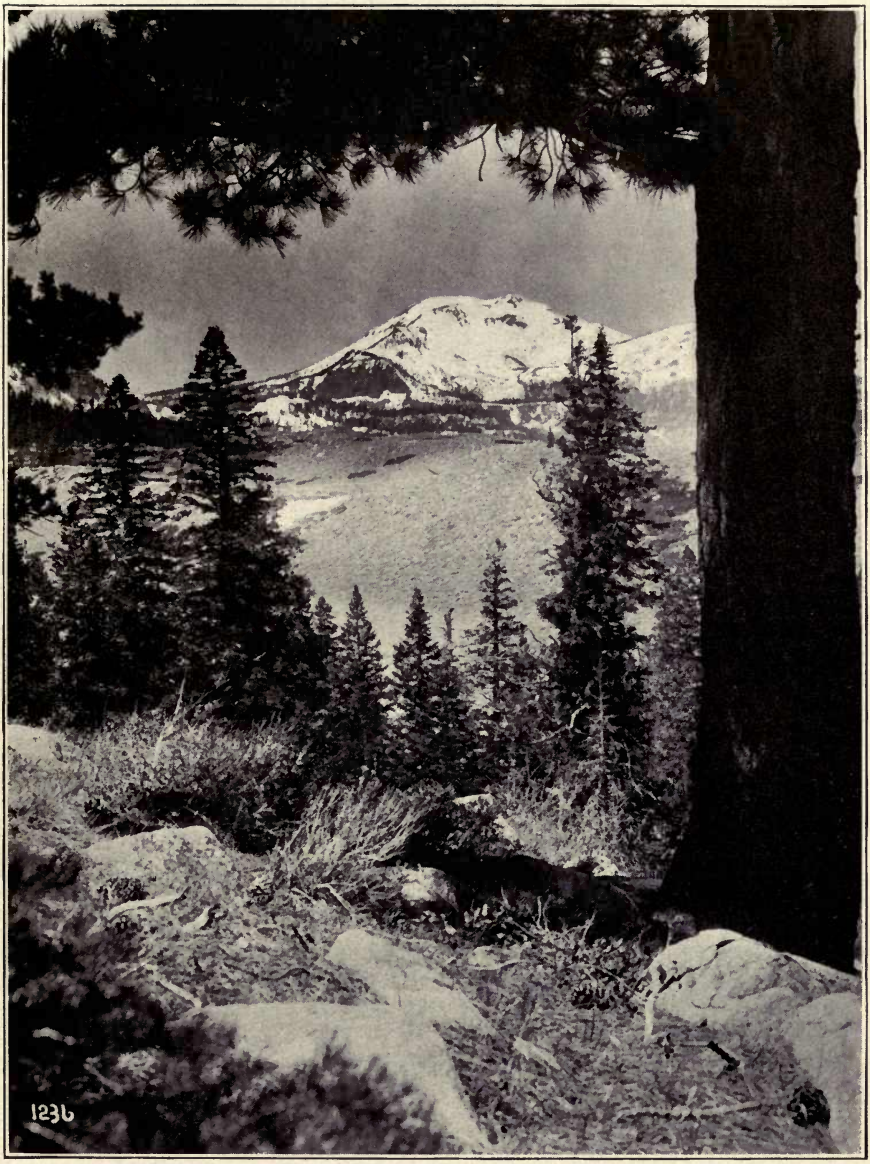
## THE AQUEDUCT SYSTEM FROM A SANITARY STANDPOINT

### LONGEVITY OF PATHOGENIC BACTERIA.

It is apparent that if, under all circumstances, the length of time required for any water supply to pass from the last possible source of



LOST LAKE AND MT. MORRISON
(TRIBUTARY TO THE OWENS RIVER)




MAMMOTH MOUNTAIN FROM LOST LAKE TRAIL
(PART OF OWENS RIVER DRAINAGE AREA)

pollution to the point of distribution and use is greater than the longevity of pathogenic organisms under the environmental conditions which obtain, then such a supply must become safe. The result is the same as that which would be secured by other processes, as by filtration or chemical disinfection. Herein lies the fundamental principle of the purification of water supplies by storage.

The pathogenic bacteria are, as a class, used only to the rich warm juices of the animal body. If, perchance, they are cast into the relatively cold environment of a body of water they are at once confronted with conditions which are unusual and untoward. They cannot long survive.

The period representing the viability of pathogenic bacteria causing the water-borne diseases constituted one of the chief features of contention between the parties during the hearing of the cases in question. The evidence seemed to be overwhelming (and even the experts for the plaintiff could not but acquiesce if the opinions of the authorities which they themselves cited, may be relied upon) that the life of such organisms, even of the resistant minority, so-called, must be very brief. All recent experiments and investigations, conducted under modern laboratory procedure and having due regard to the conditions actually prevailing in nature, demonstrate that the great mass of typhoid bacilli introduced into an ordinary surface water supply die out in a very few days, say two or three, and that all are destroyed within, say, two weeks. A storage period of three weeks or a month would surely be sufficient to insure the destruction of all bacteria causing the group of diseases in question. Of these diseases typhoid fever is, in America, by very far the most important. In the tropics cholera is the most dreadful water-borne disease. All available evidence goes to show that the longevity of the cholera vibrio is substantially less than that of the typhoid bacillus. Bacteria causing bacillary dysentery are probably but little, if any, longer lived in water supplies than are the typhoid bacilli.

AGENCIES OF SELF PURIFICATION.

There are many inter-related agencies or factors tending to separate and destroy any pathogenic bacteria which may enter a stored water supply. Those which seem to be the principal factors may be enumerated as follows: (1) devitalization, the general result of an unfavorable environment; (2) dilution or separation, reducing the number of organisms per unit of volume; (3) equalization or the tendency to produce uniformity in numbers and conditions; (4) sedimentation, both in the presence of particles of considerable subsiding value and without; (5) the inhibiting and destructive action of sunlight; (6) the inhibiting and devitalizing effect of relatively low temperatures; (7) low or different and always unsuitable food supply; (8) the inhibiting and destructive effect of the toxic products of saprophytic bacteria; (9) the ill-defined action of osmosis. The net result of the action and inter-action of these several factors may be summed up in the term "general unfavorable environment." In considering the efficiency of storage in the destruction of pathogenic bacteria, it is only necessary to insure that the time factor is sufficient; in other words, that the time elapsing be so great that any disease producing bacteria discharged from the human organism will be destroyed before those same germs can be re-ingested by

other human beings. The expression "those same germs" is used advisedly since all the evidence at hand shows that under the environmental conditions herein considered, the pathogenic bacteria in question cannot multiply or produce their kind. The problem, therefore, becomes one of destroying certain bacteria which are extremely sensitive to environmental conditions and which cannot long survive those which are untoward.

## RESERVOIRS AS SANITARY SAFEGUARDS AND PURIFYING AGENCIES.

A chain is only as strong as the weakest link determines; a reservoir, as respects the destruction of pathogenic bacteria, is only so safe as the minimum time factor represents. Most storage reservoirs are filled directly by the tributary streams from their own immediate watersheds. Very many of these are subject to "short-circuiting" by floods, which pass rapidly through them, or by waters, contributed from portions of their watersheds, which are concentrated close to their outlets. Thus, one of the most notable reservoirs employed for domestic water supply purposes in California has a capacity represented by fully 500 days of the safe yield of the catchment area, yet during maxima floods there has been wasted over its spillway in two days' time a volume of water equivalent to the entire reservoir prism. Again, one of the lakes repeatedly referred to in the testimony in behalf of the plaintiff as having been short-circuited by wind action, has 5% of its total drainage area tributary in the immediate vicinity of its outlet where the water works intake was located. About 14% of the drainage area was tributary at a point three miles from the intake in question, the lake being eleven miles in length. Approximately 22% of the watershed area was tributary to the shores of the lake through very large numbers of small water courses. The lake shores are populated by large numbers of summer residents and the entire drainage basin is comprised in a farming community and probably supports no less than forty persons per square mile, representing nearly thirty times the average density of population on the drainage basin tributary to the Los Angeles aqueduct.

The possible effects of wind in tending to induce short-circuiting in reservoirs received much attention on the part of the witnesses for the plaintiff. It naturally was attempted to make as much of this matter as possible. The conditions of shape, depth and topography of the surrounding country at Haiwee Reservoir did not, however, lend themselves readily to such arguments as these witnesses were able to offer. Indeed, such experiments and observations as could be made at the reservoir with reference to this general matter seemed to weaken rathen than to support the theories advanced.

Notwithstanding the limitations to which storage reservoirs in general are subject, the available information shows that they are in general among the greatest of sanitary safeguards for water supplies; and supplies derived therefrom are, on the average, fully as safe if not actually safer than the effluents of modern water purification plants of various accepted types. Of the fifty cities in the United States having in 1910 populations of 100,000 or over, eight have water supplies which are protected and purified by storage alone, and eleven others either have safe ground water supplies or else are sterilizing their supplies, in some cases subsequently to filtration.

COTTONWOOD LAKE REGION, JUNE 7, 1915
(TRIBUTARY TO THE LOS ANGELES AQUEDUCT)

The average typhoid fever death rate per 100,000 for the five-year period 1909-1913 for the first group of eight cities was 8.0 while that for the second group of eleven cities was 13.2.

The typhoid fever death rate in forty-three cities and towns in Massachusetts whose water supplies are purified by storage alone was only 8.08 per 100,000 for the three-year period 1910-1912. The average rate for the entire state during the same period was 9.5.

## NATURE AND CAPACITIES OF RESERVOIRS IN AQUEDUCT SYSTEM.

The general nature and capacities of the several reservoirs now built or building in connection with the Los Angeles aqueduct project have been briefly discussed in the foregoing pages. It is, of course, patent that if reservoirs are empty they become no better than stream beds and the time factor becomes little or nothing. In estimating upon the time factor which will apply to the Aqueduct works, it has been necessary to assume some storage below which the reservoirs will never be drawn. A careful study of the whole matter has led to the conclusion that Haiwee Reservoir could and should be maintained at a stage representing never less than one-half capacity and that the remaining reservoirs in the chain at stages never less than two-thirds capacity. Such assumptions require that the water resources of the system be sufficient, dependable and available upon demand. That such will be the case has been demonstrated by a long series of stream measurements and underground water investigations.

Haiwee Reservoir has in its bottom certain depressions of considerable size which are below the lowest intake level. It, therefore, can never be drained completely by gravity even if this were desired. All of the other reservoirs of the system, excepting perhaps San Fernando Reservoir No. 2, must from the very nature of their purpose, be maintained at all times as full as possible.

As stated above Haiwee Reservoir is notable from the fact that it is so very large and yet is not filled from its own watershed but only through a 60-mile line of aqueduct in which the flow is absolutely under control at all times. The maximum rate of filling, with no draft upon the reservoir—an impossible condition—cannot be more than 650 million gallons per day, equivalent to only one-thirty-second of the total capacity of this huge reservoir. There are, of course, reservoirs fed directly from their own drainage basins which do not fill and cannot be filled except in a prolonged interval. However, very few, if any, of these reservoirs receive their entire supply at one end and draw it from the other and few are as well calculated to insure total displacement in so doing as is Haiwee Reservoir. A usual case is the one cited on page 44. Another well known illustration is the Boonton Reservoir which, although fully two miles in length, receives its supply almost entirely at a point only 3,900 feet distant from the intake of the water works which is located at one end of the dam creating the storage basin.

The catchment areas of all of the other reservoirs in the aqueduct system are also small and uninhabited and the supply of water received therefrom is safe and entirely suitable for domestic purposes.

Assuming that Haiwee Reservoir is maintained at least one-half full of

water and the other reservoirs of the system (exclusive of San Fernando Reservoir No. 2) at least two-thirds full, the total minimum storage period in the system at various stages of draft or development will be as follows:

| Draft per Day | Days in Storage and Transit |
|---|---|
| 26 million gallons* | 468* |
| 136 million gallons | 122 |
| 272 million gallons | 65 |

*San Fernando Reservoir No. 1 and Lower Franklin Reservoir not in use: San Fernando Reservoir No. 2 by-passed.

By these figures it will be seen that, even with ultimate development when the draft reaches an average of 272 million gallons per day, the minimum period required for the water to pass from the inlet of Haiwee Reservoir to consumers in Los Angeles, under the assumed conditions of stage, would be 65 days. This interval is so great that there will be not the slightest likelihood of the survival of any pathogenic bacteria which might by chance enter the supply at the source. Under the draft conditions existing at the time of the hearing of the cases in question, the time interval was fully 468 days. With the works developed to one-half their ultimate capacity, the time factor in question will be fully 122 days under the conditions of stage assumed.

YIELD OF SOURCE AS RELATED TO TIME FACTOR.

Very careful series of long-time gaugings and various studies of water resources have shown that the yield of surface water from Owens River and the creeks tributary to the line of the aqueduct above Haiwee Reservoir is sufficient to maintain this reservoir at a stage representing never less than five-sixths of full capacity during the most critical period covered during the period of record (January 1, 1904 to date), when the average draught upon the system is one-half of the ultimate contemplated development, namely 136 million gallons per day. To maintain the reservoir two-thirds full during a critical period of the same severity as that just referred to when the works are developed to the point where the average draft is 272 million gallons per day will require a supplementary supply either from the ground or from storage in reservoirs constructed along the upper reaches of Owens River. It is the present intention to develop this auxiliary supply from the extraordinarily large underground resources of the Independence region by means of wells. It would also be completely possible to develop it, it is believed, through the storage of flood waters in the proposed Long Valley and Tinemaha Reservoirs, one or both, as might be found needful. The opportunities for such storage, especially in Long Valley, appear to be remarkably good.

To maintain Haiwee Reservoir half-full of water under the conditions stated will demand a maximum rate of supplementary feeding (from wells or other storage) of about 140 million gallons per day. The average daily demand during this most critical period would be about 75 million gallons. An extended series of observations in Owens Valley (see United States Geological Survey Water-Supply Paper No. 294) has demonstrated conclusively that a system of wells can readily be developed to yield the total quantity of water demanded by the conditions in question at the maximum rate just noted. The storage and underground water studies forming the basis of conclusions just stated were made by Mr. Charles H. Lee.

The sound deduction from all of these studies whose results were largely presented in the city's behalf during the hearing before Judge Works, must be: (1) that the storage may readily be maintained at the stages assumed during the most critical period covered by the record to date—and this period, September 3, 1912, to October 31, 1913, must be regarded as representing an extraordinary drought such as has probably seldom occurred in California in modern times—and (2) that, if such storage is maintained, the time factor will be so great as to represent the highest possible efficiency in the destruction of pathogenic bacteria, should they appear in the sources of supply, thereby rendering the water safe and wholesome when delivered to consumers in the city.

## QUALITY OF WATER FROM AQUEDUCT SYSTEM.

### CHEMICAL COMPOSITION OF WATER.

The witnesses for the plaintiff notwithstanding, it seems to be perfectly true that all up-to-date competent authorities are now agreed that organic matter in water, at least in any reasonable amount which is likely to obtain in surface sources, even those which are heavily charged with sewage, is quite without significance if harmful bacteria are absent. Chemical analysis is unable to give any definite information with respect to the character or number of bacteria present. It may be concluded that the so-called sanitary analysis, which attempts to determine the amount and state of nitrogenous matters dissolved or suspended in the water, has practically served its day and, except in certain routine work and for special cases and conditions, must be relegated to the past. Nowhere else does the impossibility of consistent interpretation of this sanitary analysis appear quite so prominently as in so-called expert testimony where the parties to the suit on the same data are trying to demonstrate different conclusions.

The attorney for the plaintiffs spent a great deal of time during the hearing of the cases in question upon the results of certain chemical analyses collected from the aqueduct system and from Owens River and its tributaries at various points on two different occasions. The learned witnesses who interpreted the results of the analyses pronounced the water from Haiwee Reservoir and all points below as entirely unsafe and unfit for drinking purposes. They pictured the horrible ptomaine and toxic catastrophies which would visit death and destruction upon the innocent inhabitants of Los Angeles should the wicked Board of Public Service Commissioners permit this vile fluid to be supplied for domestic uses.

As a check upon the analyses produced by these experts, the analysts for the city also collected water from the various parts of the system and made these so-called sanitary analyses upon them. The results of the two groups of analyses were not hopelessly different if exception is taken with respect to the results of certain analyses which one of the witnesses for the plaintiff made on samples which were stored for as many as ten days before the analytical work was performed.

It may be interesting to compare the analyses of samples collected at the intake of the aqueduct on Owens River with those of Massachusetts water supplies derived from 153 surface sources for which records extending over long periods have been systematically obtained. The average analyses

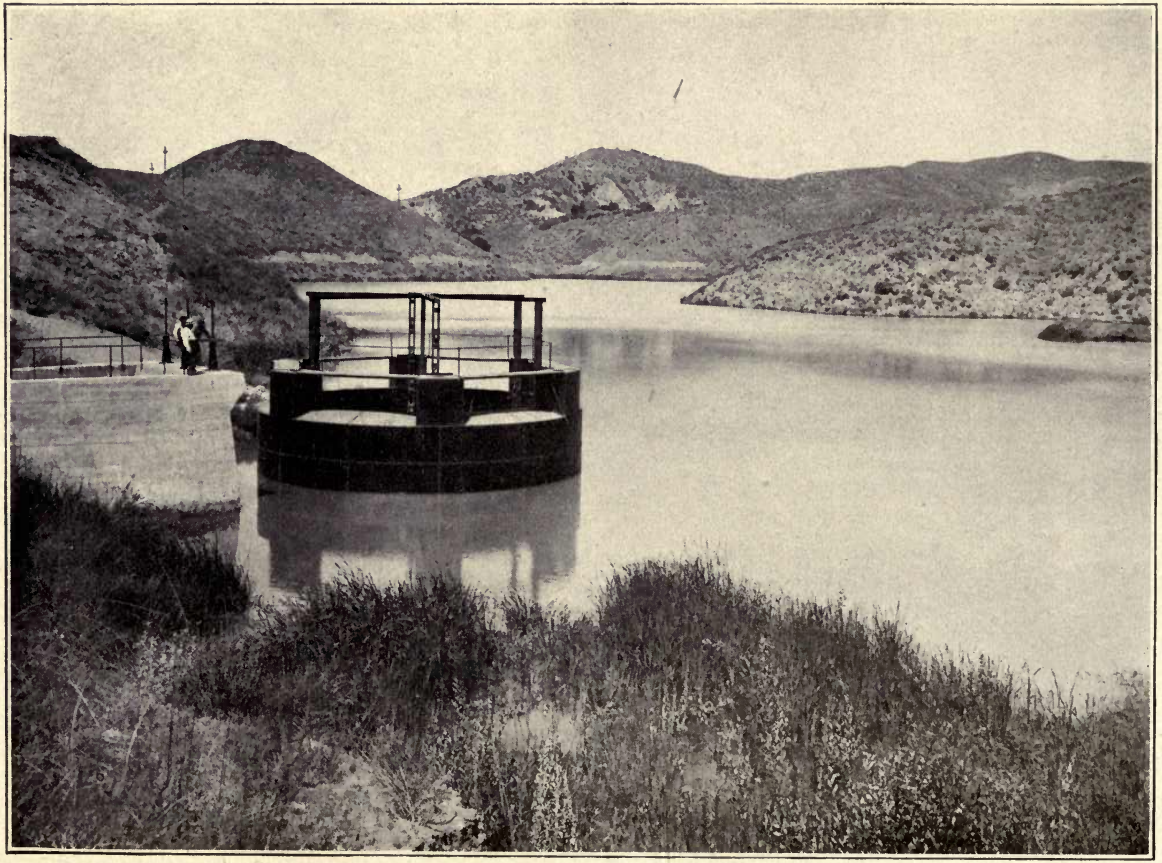
for the five-year period 1905-1909 for 110 sources out of the total number of 153 were as high or higher with respect to free ammonia, 144 sources were as high or higher as respects albuminoid ammonia and 15 sources were as high or higher with respect to nitrates. The nitrite content of surface waters was not summarized in the Massachusetts statistics referred to (41st Annual Report, Massachusetts State Board of Health, 1909, pages 201-225), perhaps because it was too variable and uncertain to be of interest.

The results of analyses of samples collected further down in the system, near the point of distribution, namely in the section between the San Fernando Reservoirs and Franklin Reservoirs, may be of interest as compared with the results for the same group of Massachusetts surface water sources above referred to. Of the total of 153 sources represented, 14 were as high or higher with respect to free ammonia, 58 as high or higher with respect to albuminoid ammonia and 3 as high or higher with respect to nitrates. No one has ever discovered or complained that the state of health in the various communities having these higher amounts of nitrogenous material in their drinking waters was not fully as good as that in the communities having water supplies extraordinarily low in organic composition.

In order to show what effect, if any, the drinking of waters heavily charged with organic matter might have upon the health of consumers as compared with those low in organic content, the general death rates in 15 Massachusetts cities and towns deriving their water supplies from storage reservoirs containing the largest amounts of albuminoid ammonia and high free ammonia were compared with those of 15 other cities and towns in Massachusetts whose water supplies from storage reservoirs were generally lowest in albuminoid ammonia and low in free ammonia. The analyses and vital statistics covered the same period, namely the five-year period 1905-1909, inclusive. The study showed that the general death rates in the two groups of cities were practically identical, being 0.01 per 1000 higher in the cities supplied with waters lowest in organic content, as represented by albuminoid and free ammonia.

The mineral composition of the water derived from the aqueduct system was not projected into the hearing of the cases. On this feature there can be no controversy. Daily samples for the entire year 1908 were collected from Owens River just above the aqueduct intake and were analyzed for their mineral composition in 10-day composites in the laboratories of the United States Geological Survey. The water was found to carry only 16 parts per million of turbidity. The suspended matter causing the turbidity was found to be extremely coarse and capable of settling almost completely out of the water in a very short period. The average turbidity is only 13% of the average of the Sacramento River at Sacramento, 15% of that of the Potomac River at Washington, 30% of that of the Susquehanna River at Harrisburg, 41% of that of the Delaware River at Philadelphia and 55% of that of the Hudson River at Albany. The maximum turbidity of Owens River water was found to be only about 3 or 4 times the average. The maxima turbidities of all of the streams mentioned above are many times the average values for these rivers.

The total hardness of the water of Owens River was shown not to be excessive when compared with that of the majority of the water supplies of



DRY CANON RESERVOIR

the municipalities in California. The supplies of Alameda, Berkeley, Fresno, Oakland, Pasadena, Redlands, Riverside, San Bernardino, San Diego, San Francisco and Stockton all have an average total hardness greater than that of Owens River. The Los Angeles River supply at the headworks has a total hardness 150% greater, and at Crystal Springs a hardness 67% greater than that of Owens River water.

BACTERIOLOGICAL COMPOSITION OF WATER.

All analyses show that at the inlet of Haiwee Reservoir the aqueduct supply contains considerable numbers of bacteria of the species developing on agar at 37° C. In the eight samples taken by the analysts of both parties to the suit and whose analyses are available, the numbers ranged from 50 to 2100 per cc. Four, or 50%, of the samples were negative for B. coli. In two of the other samples the organism was present in 10 cc. and in the remaining two samples it was present in 1 cc.

Eight samples of water were collected for bacteriological analysis at the intake of Haiwee Reservoir by Messrs. Wilson and Brem for the city. The counts on agar ranged from 60 to 1800 per cc. and averaged 800. B. coli was not found in any of the samples. The analysts for the plaintiffs in the two sets of samples collected at this point succeeded in finding B. coli in 0.4 and 0.5 cc.

On general principles, as enunciated above, it is obvious that real interest should center in the bacteriological character of the water of the Aqueduct system as delivered to consumers in Los Angeles. Many samples of water were collected by the analysts for the City at various times at points carefully selected to represent as comprehensively as possible the entire area in the city supplied by the Aqueduct works. These were all examined in accordance with the most rigorous procedure with the following results:

| Name of Analyst | No. of Samples Examined | Average Total Count* | B. coli | | |
|---|---|---|---|---|---|
| | | | Neg. in 10 cc. | Pos. in 10 cc. | Pos. in 1 cc. |
| Black | 13 | 60 | 12 | 1 | 0 |
| Brem | 23 | 210 | 15 | 8 | 0 |
| Wilson | 23 | 330 | 21 | 2 | 0 |

*On agar at 37° C., 24 hours.

The results are surely very satisfactory. B. coli, the typical intestinal organism of both man and animals, were not found once in 1 cc. in the 59 samples represented. They were found in 10 cc. portions of 11 samples or in about 23% of the entire number examined. Considering the newness of the reservoirs, the large numbers of water fowl thereon and the (temporary) exposure to animal contamination in San Francisquito Canyon, it seems wholly reasonable to conclude that the intestinal organisms found were entirely from animal sources and had no sanitary significance.

The significance of the presence of B. coli in a water supply rests, of course, in the fact that if intestinal germs are present from human sources, the pathogenic bacteria which cause the water-borne diseases may also be present. In so far as the opinion of sanitarians has been crystalized at all with respect to the significance of B. coli in surface waters, it would seem to be that the occasional presence in 10 cc. or even in 1 cc. has but little

sanitary significance. If this organism is persistently present in 1 cc. of samples examined there is good ground for the belief that the source is no longer harmless animal pollution but rather the more constant and dangerous wastes from human beings.

An interesting side light was thrown upon the theory that water fowl might be responsible for the B. coli found in the waters of Franklin Reservoir and in part for those found in the other storage basins of the system. Two wild duck were shot in Upper Franklin Reservoir and their intestinal tracts were examined for B. coli. This organism was present true to type in enormous numbers in each case, the average being about 50,000,000 per gram of dejecta in the intestinal canals.

It is a striking and significant fact that the chief witness for the plaintiff made no bacteriological examinations whatever of the water from the Aqueduct system as delivered to consumers in Los Angeles. Two samples only were reported by another witness. Both samples were taken at the same date at the residence of E. M. Frost. The total count was given as 110 per cc. (presumably after 72 hours incubation at 37° C. on agar). B. coli were reported as absent in 5 cc. of one sample and as identified in 1 cc. of the second sample. It is difficult to state how much value may be placed upon the work of this witness since, during cross-examination in the hearing before Judge Works, she naively admitted that she had been employed to find pollution and that samples which did not show such conditions were discarded.

## POSSIBILITY OF DISINFECTION OF ENTIRE WATER SUPPLY.

It has now become possible to effectively disinfect public water supplies in the largest volumes at an extremely low cost and with the minimum of attention employing either liquid chlorine or hypochlorite of calcium (bleaching powder). If at any future time it is desired—for aesthetic reasons or to "make assurance doubly sure"—to virtually sterilize the water by either of the methods stated, it can be done. The conditions at Lower Franklin Reservoir are ideally devised for such treatment so that the water entering the distribution system from the Aqueduct system may be rendered not only practically free from B. coli, as at present, but also practically free from all bacterial life.

Chlorination of the supply from the Los Angeles River works has now been undertaken and is producing excellent results. All bacteriological samples collected from this source during the preparation of evidence for the hearing of the cases in question and prior to the installation of chlorinating devices were found to contain B. coli. These were present in 91% of 1 cc. samples and in 10 cc. of all samples.

## THE AQUEDUCT SUPPLY AS FULFILLING RIGOROUS QUALITY REQUIREMENTS.

In the earlier days of water works engineering but little attention was paid to the sanitary character of the supply. The principal object was to secure a sufficient quantity of water. Gradually, with the development of a knowledge of bacteriology and a growing appreciation of the intimate relationship between water supplies and disease, the demand has arisen not only for abundance but also for safety and aesthetics as comprehended by

freedom from disease germs and as far as possible from all bacterial life and by good appearance and taste. Today the requirements of quality and quantity must be considered of equal and absolutely essential importance. The failure of a water supply to meet either of these fundamental requirements must be considered as a real delinquency entailing a definite burden which must be borne by the community.

The production of safety as well as of good appearance in a public water supply has a sanitary and aesthetic significance which cannot be measured by any financial standard, important as this may be. The real test is not the quality at the source; it is the quality at the point of use. These finer qualities in a water supply bespeak progress, they imply additional safety and comfort in living and in so far as water supplies have to do with these matters, purity means better general health, a real conservation and promotion of those forces which may be regarded as the vital assets of the community. Indeed, the simple fact that its water supply is at all times safe, wholesome and attractive, rather than dangerous and of ill appearace, is an asset of very material worth to any community.

The opinion of sanitary engineers, sanitarians and in general those who are familiar with the development of water supply standards, has now become crystalized with respect to the requirements which the supply and works must fulfill. These requirements are sanitary, aesthetic, commercial and protective in their nature. They may be summarized as follows:

(a) Quality—

(1) Primarily the water supply must be free from pathogenic or disease producing organisms. More than this, it should be free from those allied organic forms which may not as yet be recognized as accompanying disease, but which may nevertheless not be conducive to health. This condition of safety must prevail continuously and the supply must not be subject to what may be termed "accidental" contamination.

(2) The water must be uniformly clear and free from turbidity, both that which may be produced by suspended mineral matters, and also that which may be due to suspended organic (vegetable and animal) growths or impurities.

(3) The water must not be discolored by dissolved vegetable matters to such an extent that it may be objectionably apparent when employed for table use or in the arts.

(4) The water must at all times be free from both tastes and odors, either those produced by dissolved gases or those which may be due to the growth and decay of micro-organisms (minute plants and animals frequenting lakes, reservoirs and rivers, but usually prevailing to the least extent in the last named source).

(5) The water should be reasonably soft and of sufficiently low mineral content so that it shall be satisfactory in this respect not only for domestic purposes but for steam making and other industrial and commercial uses.

(6) As far as possible the water should be cool and palatable.

(b) Quantity—

(7) The supply must be abundant and unfailing, but for economic reasons must be conserved in such manner that all preventable waste shall be eliminated.

(c) Dependableness—

(8) The pressure under which the water shall continuously act in the distribution pipes must be ample to serve the various districts according to their specific character and needs.

(9) The system of works must be one in which design and construction may be executed in such a way that they will successfully meet conditions imposed by the natural phenomena occurring or likely to occur within the region in question.

(10) The various structures in connection with the system of water works should be so located, arranged, built and protected that they may not be unduly exposed to fires or other accidents befalling neighboring structures.

The requirements which have been outlined above are not more exacting than the principles of sanitary science, aesthetics, economics and safe engineering demand; in fact, they are only rational requirements upon which the public at large, gradually educated to higher ideals, will become more and more insistent as time goes on.

It is pertinent to inquire how completely the character and conditions of the Aqueduct supply at the point of use do and will measure up to the ideal standards pronounced above. With respect to the several qualitative standards we may conclude:

(1) That the supply is now and will remain at all times practically free from all pathogenic bacteria. If chemically treated according to recently devised, cheap and readily applicable methods—to which the distributing works are peculiarly well adapted, as explained hereinbefore—it will become practically free from all bacterial life. It may safely be assumed, however, that the present bacterial composition is not unsatisfactory and is entirely without sanitary significance. As soon as the "newness" of the reservoirs wears off and the permanent shore lines become established there is not the slightest doubt but that the ordinary bacterial content of the supply will be naturally and substantially decreased.

(2) That the water delivered to consumers is and will be clear, and especially so when, with increasing age, the permanent shores of the reservoirs become established. Lower Franklin Reservoir, which is the last in the series in the Aqueduct system and wherein the water is stored immediately before it is delivered to consumers, is ideally contrived to prevent the growth of algae and other micro-organisms, as well as of bacteria, by the use of chemicals.

(3) That the water of Owens River and its tributaries is practically colorless and free from vegetable stain. There is no reason to believe that its character in this respect will deteriorate in passing through the Aqueduct system.

(4) That under the conditions which do and will obtain, and in view of the fortunate situation with respect to Lower Franklin Reservoir as just noted in (2) above, the aqueduct supply will always be satisfactory from the standpoint of odors and tastes. All storage reservoirs are more or less subject, at intervals, to the growths of micro-organisms. By modern methods these can be effectively controlled.

(5) That as noted on page 49, the aqueduct supply is much softer than the supply derived from Los Angeles River. It is softer than the majority of the water supplies of the larger cities in California.

(6) That the conditions as respects coolness are matters dependent upon the climate and the depths to which the water mains are laid. With the control of growths of micro-organisms in the reservoirs, and particularly in Lower Franklin Reservoir, there is every reason to believe that the water will continue to be palatable as it is at present.

The water resources of the aqueduct system have been discussed at some length in the preceding pages. All of the studies which have been

made demonstrate that the volume of supply for which the system has been designed can be developed and can be maintained at all times and under all conditions.

It is not the purpose of this paper to discuss the structural stability and other features having to do with the dependableness of the works. Most of the structures have already been tested through a considerable period. They have proved their ability to stand and to perform the service for which they were intended. Indeed, it can be stated without reservation that this magnificent enterprise, now all but completed, has been carried through in a marvelously enduring fashion with an economy which has won the enthusiastic praise of the whole engineering world.

## CONCLUSION.

### DECISION OF JUDGE WORKS.

No more suitable or fitting conclusion to this discussion could be offered than the decision of Judge Lewis R. Works before whom, in Department Four of the Superior Court of Los Angeles County, the cases of Hart and Frost vs. the City of Los Angeles were heard. The written decision was rendered shortly after the arguments of counsel were concluded. The text of the decision is as follows:

> "This litigation was instituted for the purpose of enjoining the further delivery of a water supply from Owens Valley to the people of Los Angeles. It proceeds mainly upon the claim that the water is polluted and infected, is likely to continue so, and is therefore unfit for human consumption. This claim has been urged strenuously throughout the trial and the defense waged against it has been equally vigorous. Counsel on both sides have been vigilant, aggressive and untiring throughout the controversy. One hundred and fifty photographs and maps have been introduced in evidence and about three hundred samples of water, taken at various points from the headwaters of Owens River to kitchen taps in Los Angeles, have been analyzed for the information of the Court. Men and women of a high degree of learning in hydraulics, in bacteriology and in analytical chemistry have testified, the respective counsel have been allowed the widest possible range in the introduction of the evidence and the subject has been exhausted. The hearing has consumed forty actual trial days.
>
> "Owens River and its tributary creeks flow through a country given to cattle raising and other rural pursuits, and it is not denied by the defendants that these streams are contaminated to the extent that is necessarily characteristic of all waters flowing through such a country, and having a similar population. In this connection it is to be noted, however, that the watershed of the Owens River is peopled by an average of but about one and one-half persons to the square mile, while many of the cities of the world take their water supply from surface streams the drainage area of which is populated to the extent of several hundred persons to the same area.
>
> "The scientific principles governing the selection and operation of a water supply system intended to furnish a domestic supply from surface streams require a treatment of the water in order to rid it of the contamination which is inevitably incident to such a source of supply. This treatment consists in either the use of chemicals, the installation of filtration plants, or in the storage of the water in reservoirs for a period of time requisite to its purification.
>
> "If it be granted that the waters of Owens Valley are contaminated like all surface waters, the density of population of its drainage area being the true index of contamination, and if it be granted that, for

that reason, those waters would not be proper for domestic use at the intake of the Los Angeles Aqueduct, in the valley, does it follow that the water has not been purified when it reaches the point of delivery in Los Angeles, two hundred eighty-six miles from the intake? In other words, is the water, during its transmission from the intake to the City, subjected to either of the methods of treatment above mentioned as requisite to the purification of a surface water supply?

"Ninety miles from the Aqueduct intake is located Haiwee Reservoir. From the outlet of that reservoir to Los Angeles is one hundred ninety miles. During its progress over that distance, the water supply is halted, even if briefly, in Fairmont, Dry Canyon and Franklin Reservoirs, three other basins having some value for storage purposes.

"A large portion of the testimony during the trial has been directed to the question of the efficiency of the entire system mentioned, and especially of Haiwee Reservoir, as a purifying agency, and many experiments have been conducted in the waters of the reservoir in order to determine the problem. It is not necessary now to state the nature of these experiments, nor to analyze the theories and arguments advanced by the various expert witnesses who have testified concerning them. It is sufficient to say that the great weight of the evidence demonstrates that Haiwee Reservoir is remarkably efficient as a great purifying unit in the Aqueduct system. This immense basin is over seven miles in length, with that distance between its inlet and outlet, and impounds, for a long period of time, certainly not less than thirty days, all waters which enter it. The reservoir is peculiarly adapted to the use for which it was principally designed. One of the leading expert witnesses in the case characterizes it as unique among the storage reservoirs of the world. Being in a region in which there is a rainfall of not to exceed five inches per annum, a region of porous, sandy soil, and entirely uninhabited, it is the recipient of no run-off from its own watershed and it is therefore free from the contamination of such a run-off. The only influent of the reservoir is the Los Angeles Aqueduct, containing waters brought from the Owens River. The intake gates on the river may be closed at will and there are frequent waste gates along the course of the aqueduct, from the river to the reservoir, through which the waters of the great ditch may be entirely cast away. These instrumentalities conduce to a perfect control of the Haiwee influent and the waters may be diverted and wasted in periods of flood or at any other time of possible undue contamination from whatever cause.

"This peculiarly advantageous location of Haiwee is mentioned in passing, only, as the period of storage which is allowed by its size and shape is alone sufficient to guarantee to the people of Los Angeles a positive immunity from dangers residing in the waters before they leave Owens Valley, conceding that such dangers are there present, and without regard to the use of the waste gates mentioned, which furnish but an added factor of safety to a system safe enough without them.

"The Los Angeles Aqueduct is so planned as to secure to the residents of Los Angeles a palatable, wholesome and entirely sanitary water supply and Haiwee Reservoir is the prime element of safety.

"The conclusions reached in this opinion do not come from a mere preponderance of the evidence, but from an overwhelming weight of proof which leaves possible no other termination of the litigation. On the whole, the record in this trial furnishes a splendid vindication of the judgment of the people of the city in acquiring and developing a water supply from the Owens River region.

"The application of the plaintiffs for an injunction is denied and the defendants will have judgment for their costs."